ATMS Striping Mitigation Algorithm

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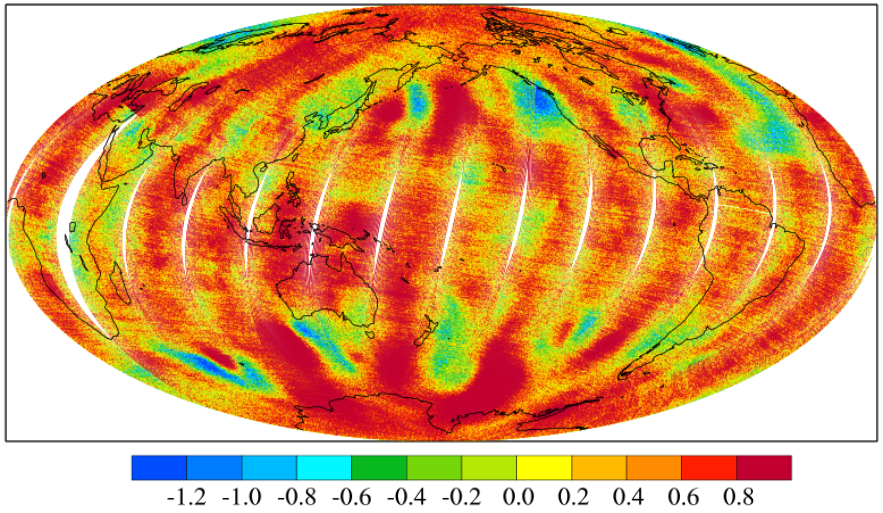
Striping Noise in Global Distributions of ATMS O-B

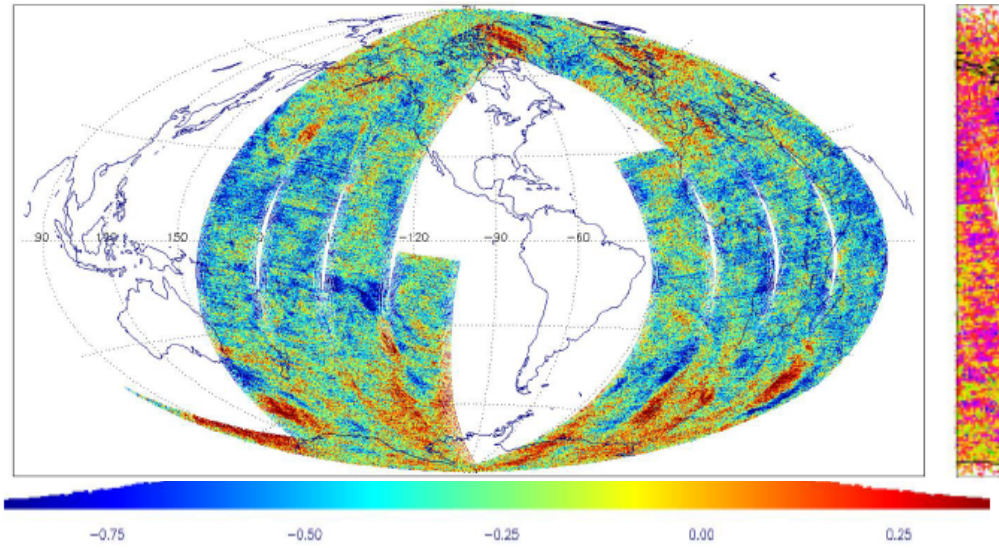
An along-track striping noise of ATMS data in NWP O-B fields!



O-B of channel 10 (86 hPa)

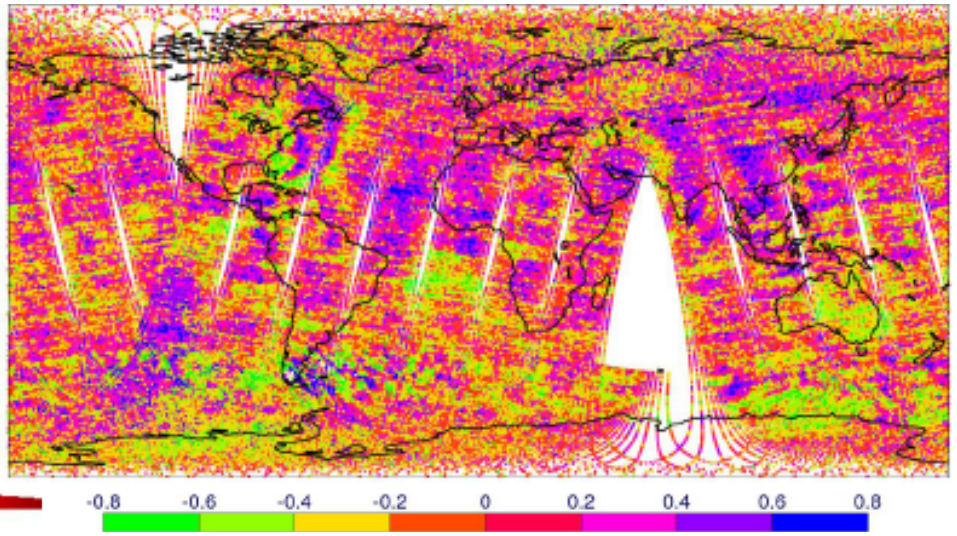
Qin, Zou and Weng, 2013, JGR

O-B of channel 8 (250 hPa)



Swadley et al, NRL

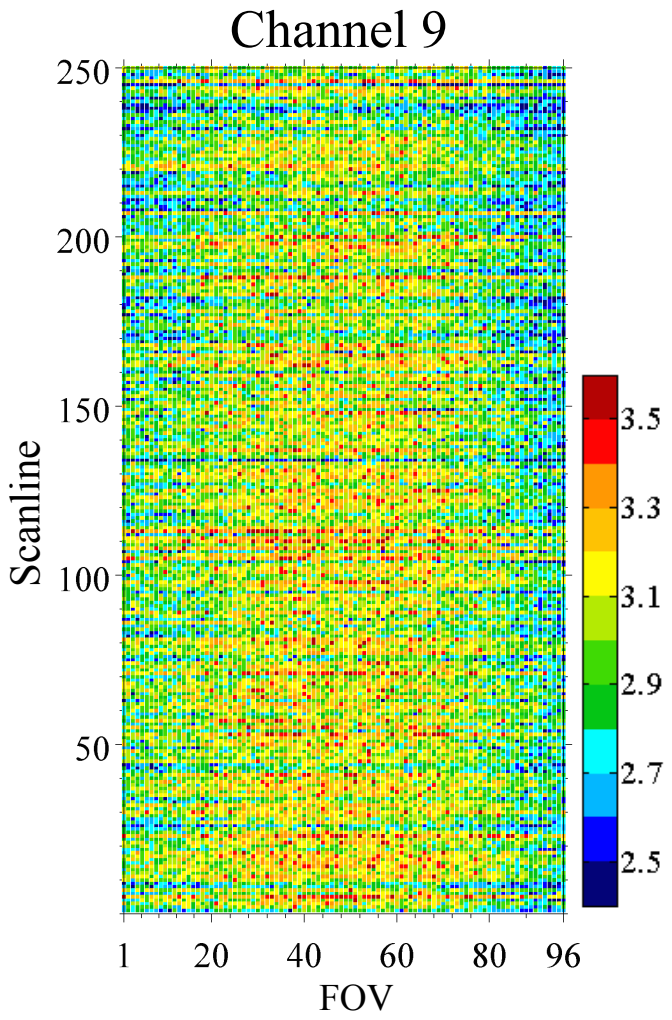
O-B of ATMS channel 12 (25 hPa)

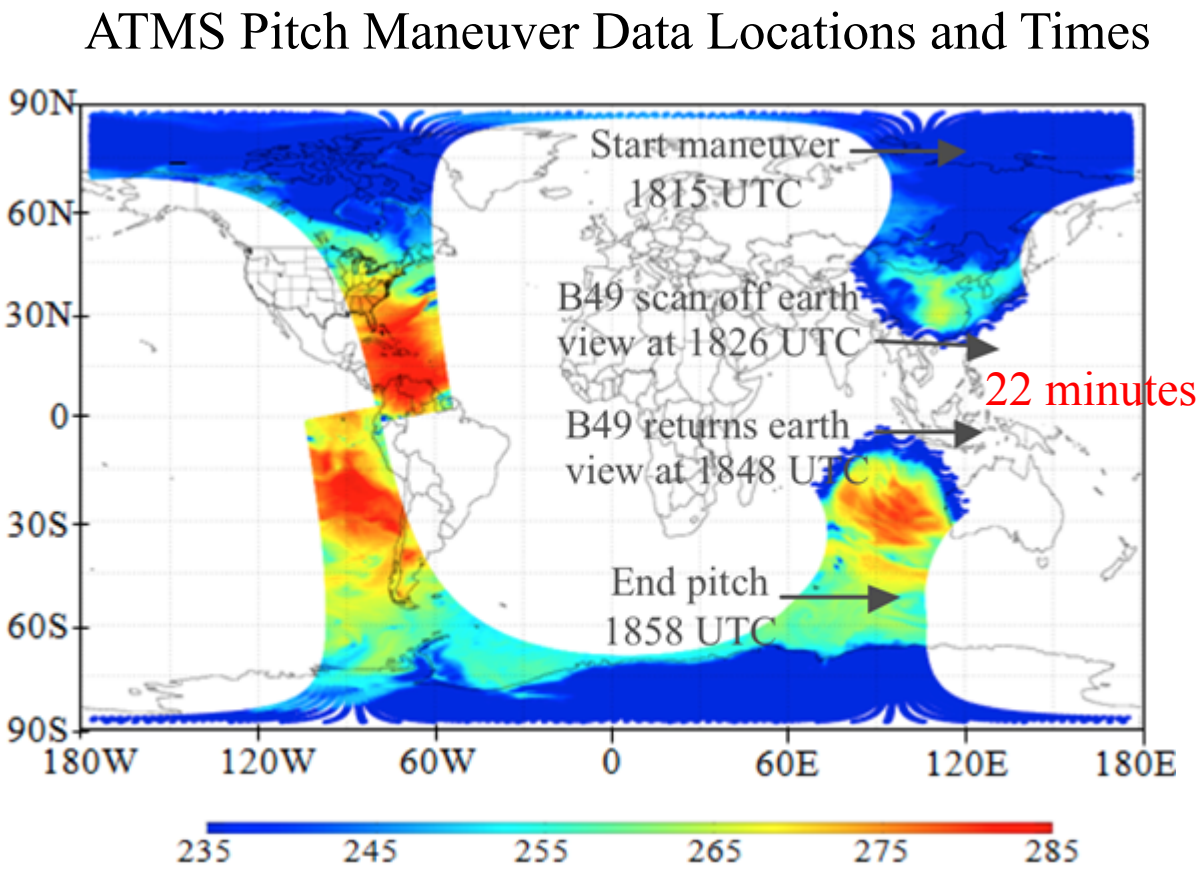


Bormann et al., ECMWF

User Complains !

Striping Noise Seen in ATMS On-Orbit Pitch Maneuver Data





The pitch-over maneuver was performed February 20, 2012.

ATMS Striping Noise and Its Impacts on Users

- SNPP ATMS upper air sounding channels display clear striping noise in NWP model O-B fields, which is disturbing and may degrade ATMS data assimilation impacts on NWP

- At the 19th International TOVS Study Conference (ITSC), NWP users request the ATMS Cal/Val team not only to quantify the striping noise magnitude but also to develop an operational algorithm for elimination of striping noise in ATMS data

- ATMS Cal/Val team was requested to develop 45 days of ATMS de-striping data for EMC, ECMWF and other NWP centers to test the impacts of striping noise on ATMS data assimilation for NWP

Requirements on Striping Noise Mitigation Algorithms

- **Characteristic features of ATMS striping noise**

  (1) Nearly constant in across-track direction for any single scan

  (2) Of random magnitude in along-track direction for any swath

- **Challenge**

  (3) Such striping noise exists in scene counts

- **Requirements on striping mitigation algorithms**

  (4) Striping noise is removed

  (5) Small-scale weather features are not altered

  (6) Feasible for operational implementation

Striping Noise Mitigation Algorithms

- The PCA/EEMD Algorithm (good for theoretical analysis of striping noise)

  Step I: Compute principal components of ATMS data matrix
  Step II: Extract the first few high frequency IMFs from the 1st PC mode to remove striping noise

- The PCA/SymFilter Algorithm (good for operational implementation)

  Step I: Compute principal components of ATMS data matrix
  Step II: Apply a symmetric filter to the 1st PC mode to filter striping noise through an "optimally" weighted averaging

PCA	—— Principal Component Analysis
EEMD	—— Ensemble Empirical Mode Decomposition
SymFilter	—— Symmetric Filter
IMFs	—— Intrinsic Model Functions

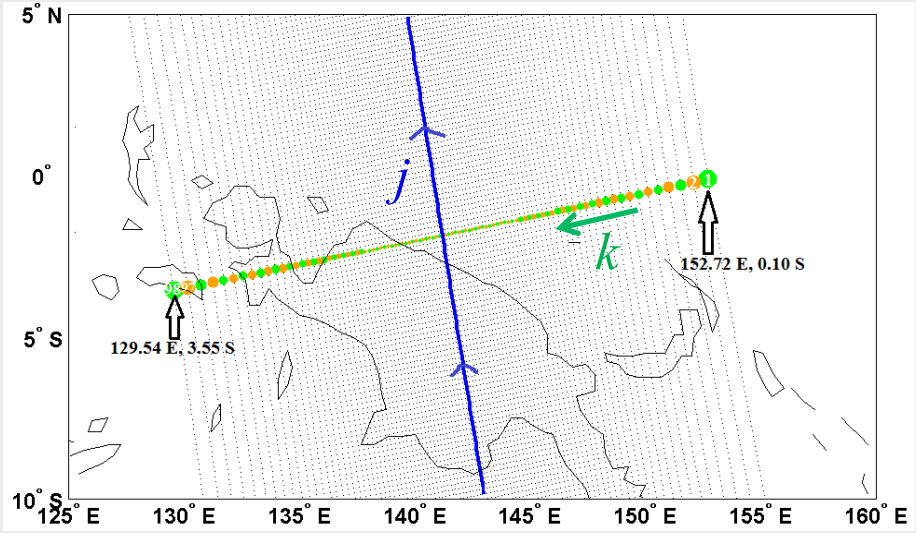
Step I: Compute PCs of ATMS Covariance Matrix

1. Form ATMS data matrix

$$\mathbf{A} = \begin{pmatrix} TB_{1,1} & TB_{1,2} & \cdots & TB_{1,j} & \cdots & TB_{1,N} \\ TB_{2,1} & TB_{2,2} & \cdots & TB_{2,j} & \cdots & TB_{2,N} \\ \vdots & & \ddots & & & \\ TB_{k,1} & & & TB_{k,j} & & TB_{k,N} \\ \vdots & & & & \ddots & \\ TB_{96,1} & & & & & TB_{96,N} \end{pmatrix}$$

k, cross track

j, along track



2. Construct covariance matrix

$$\mathbf{S} = \mathbf{A}\mathbf{A}^T$$

$$\mathbf{S}\vec{e}_i = \lambda_i \vec{e}_i$$

PC modes

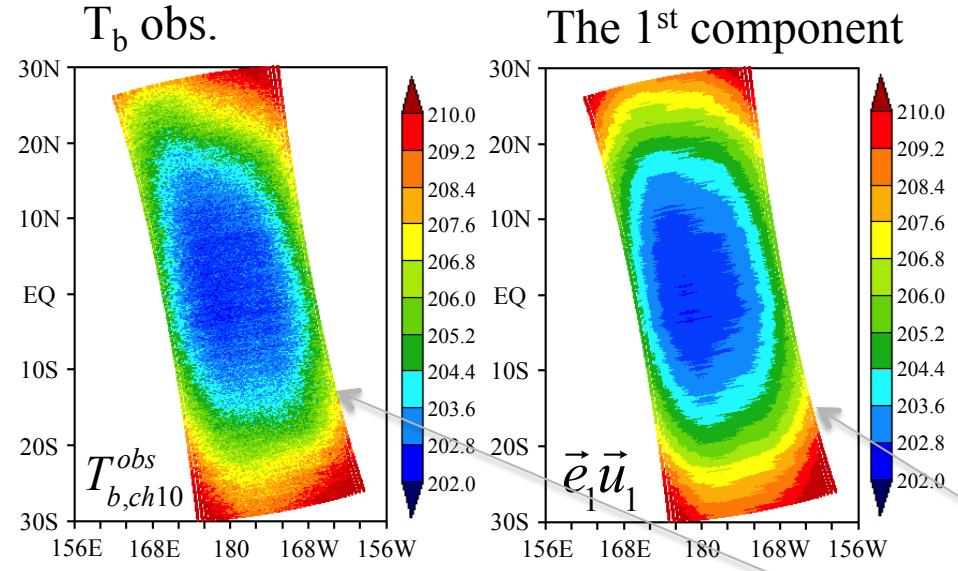
3. Mapping ATMS radiance in PC modes

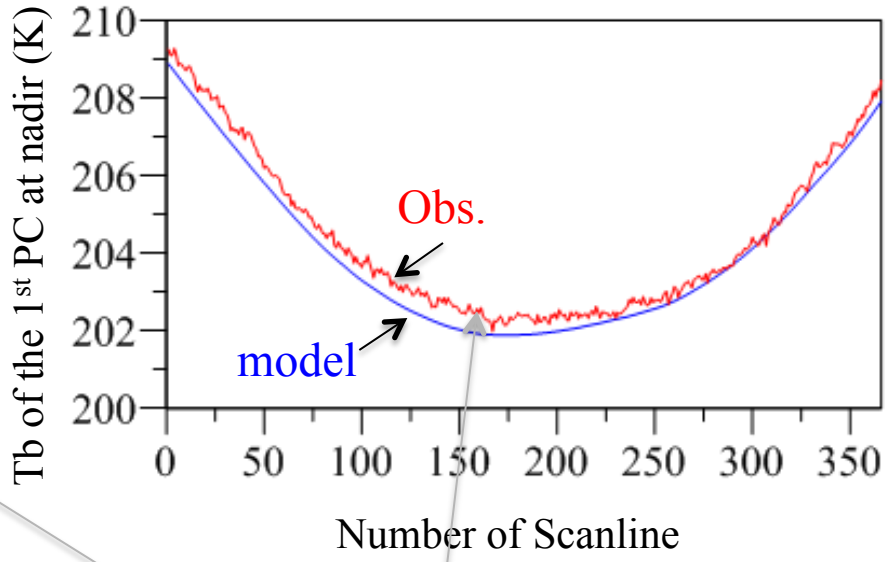
$$\mathbf{A} = \sum_{i=1}^{96} \vec{e}_i \vec{u}_i$$

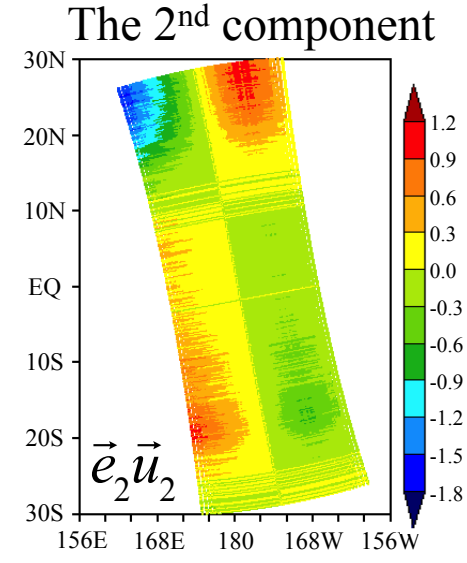
PC coefficients

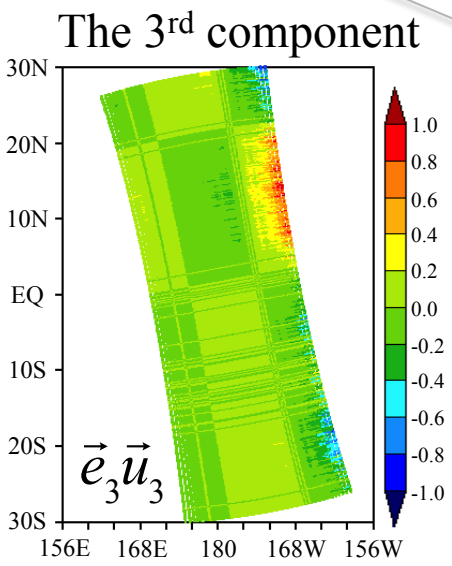
$$\begin{pmatrix} \vec{\mathbf{u}}_1 \\ \vdots \\ \vec{\mathbf{u}}_{96} \end{pmatrix} = \begin{pmatrix} \vec{\mathbf{e}}_1 \\ \vdots \\ \vec{\mathbf{e}}_{96} \end{pmatrix} \mathbf{A}$$

PCA Decomposition for ATMS Channel 10









An along-track noise oscillations are clearly seen in ATMS radiance measurements of channel 10.

Step II: Extract IMFs from the 1st PC Coefficient

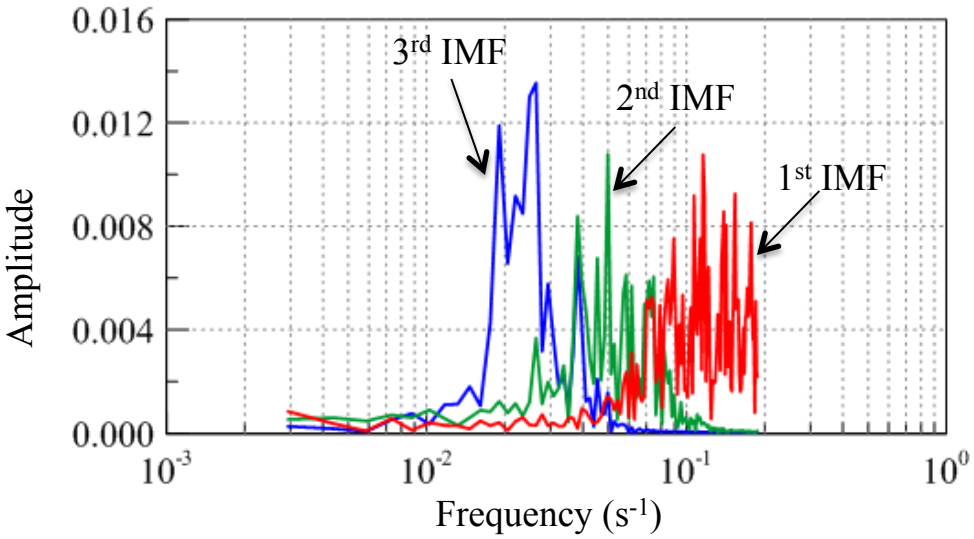
EEMD decomposition:

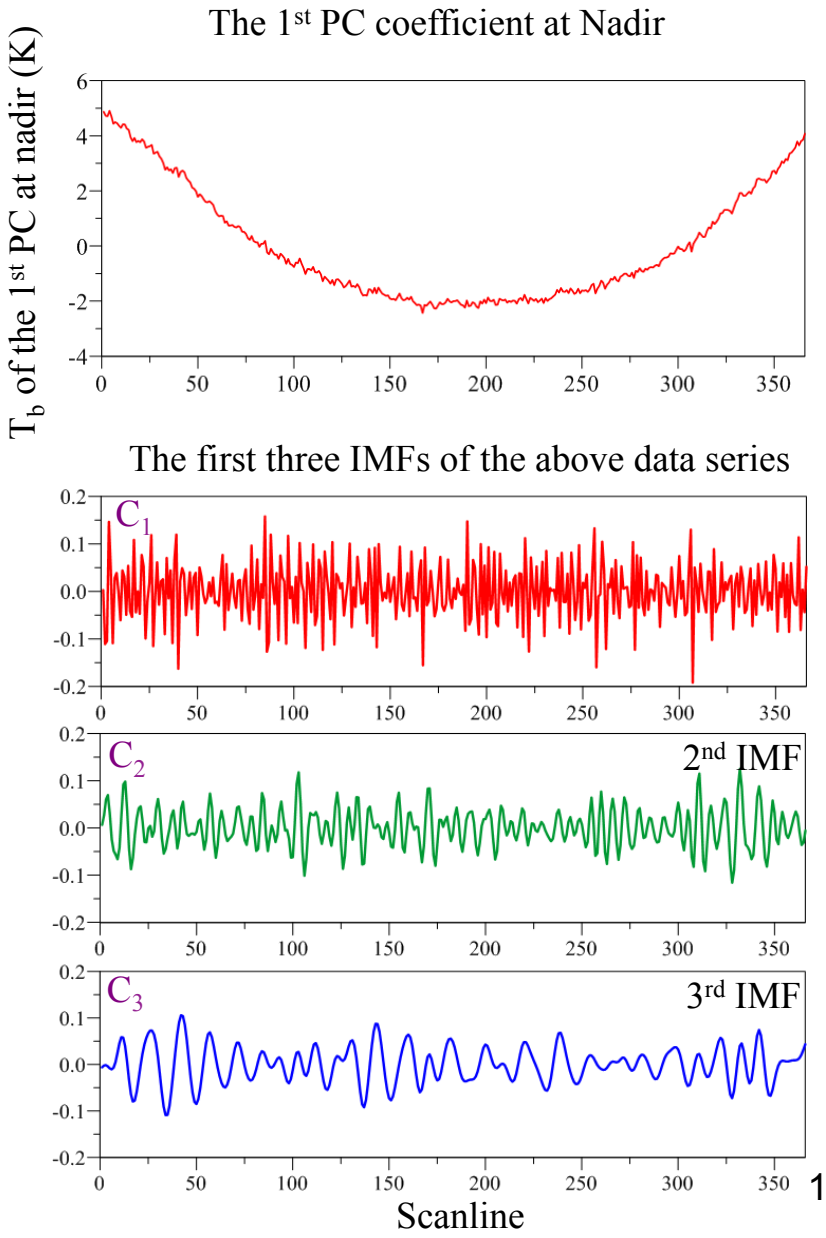
$$T_b^{obs}(t) = \sum_{j=1}^{n} C_j(t) + R_n(t)$$

$R_0(t) = T_b(t)$

$C_n \leftarrow$ R_{n-1} minus the mean of the envelopes of R_{n-1}

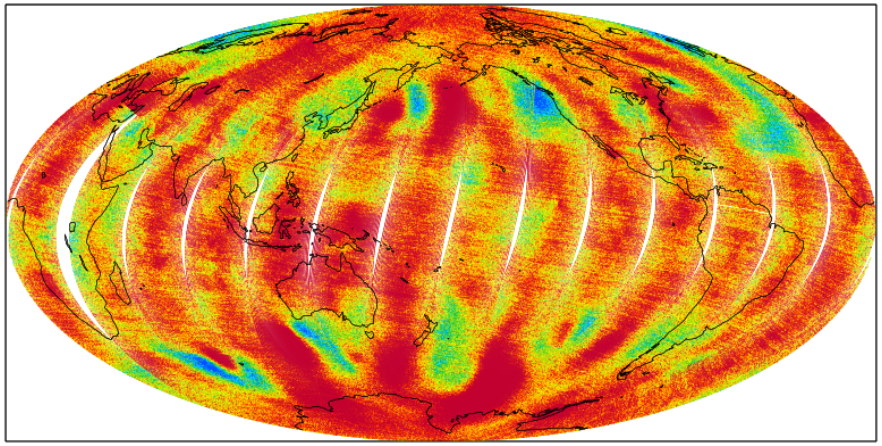
$R_n(t) = R_{n-1}(t) - C_n$



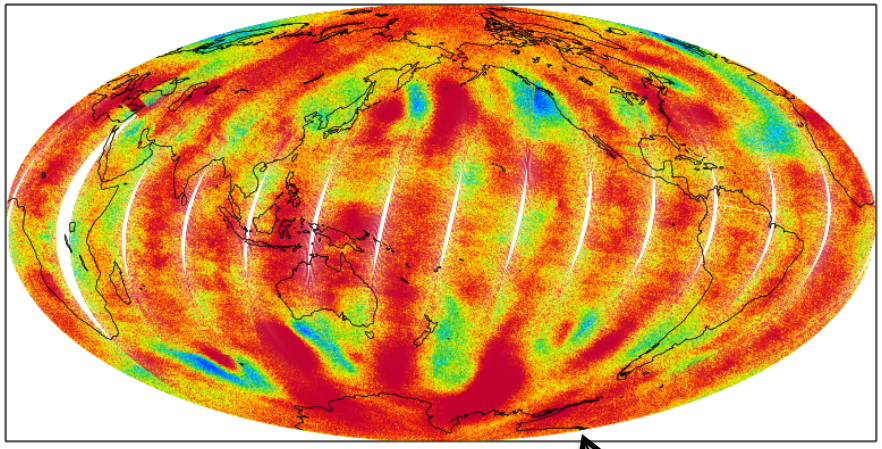


Global O-B Distributions for ATMS Channel 10

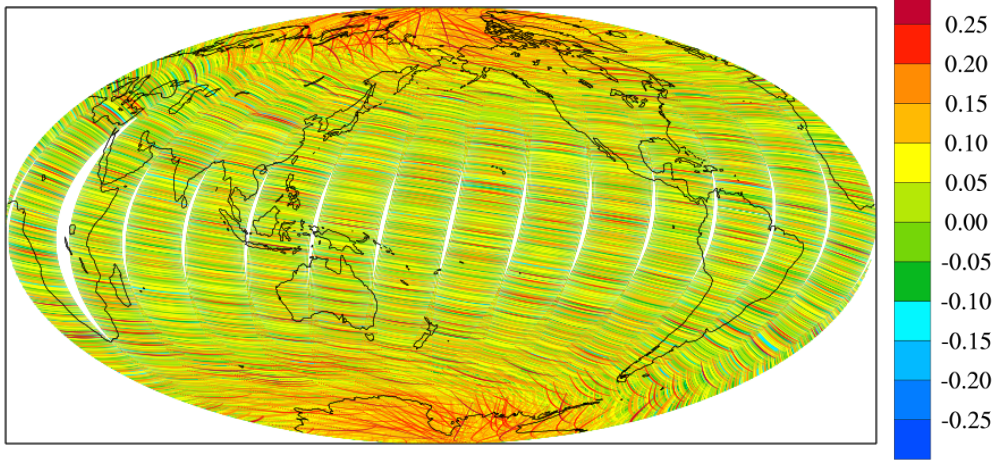
Before de-striping



After de-striping



Striping noise mitigated



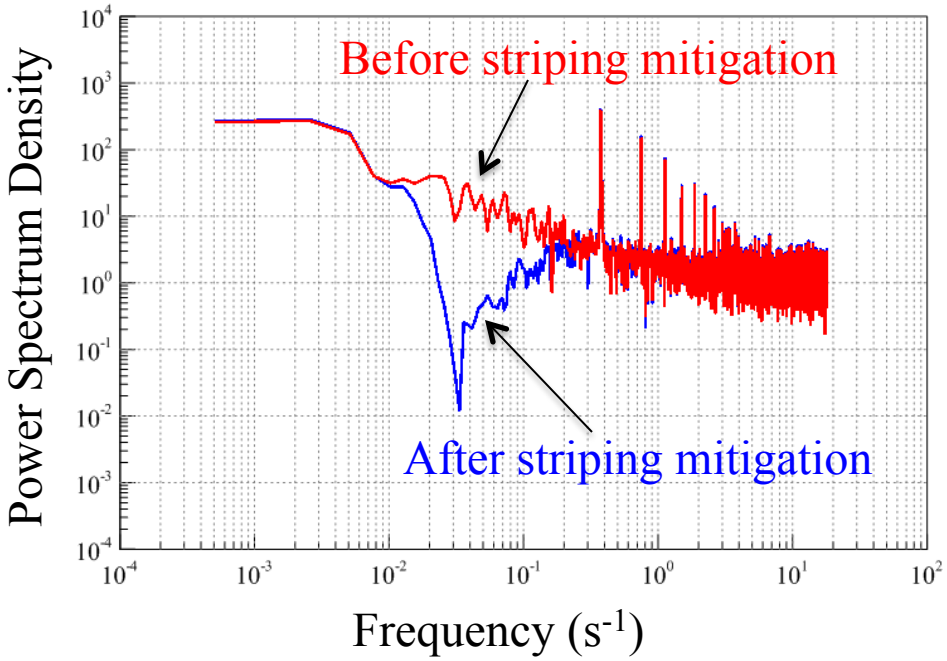
Data on 24 February 2012

Striping noise is not visibly seen anymore in the global O-B field after de-striping using the PCA/ EEMD algorithm.

Qin, Z., X. Zou and F. Weng (2013) *J. Geophy. Res.*, **118**, 13214-13229.

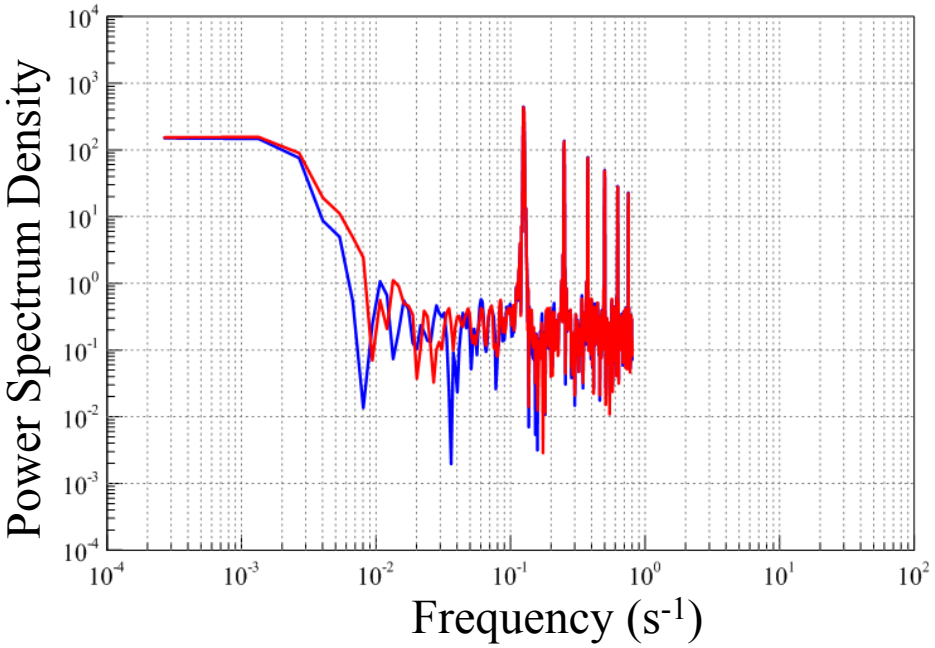
Power Spectral Density Distributions

SNPP ATMS channel 10



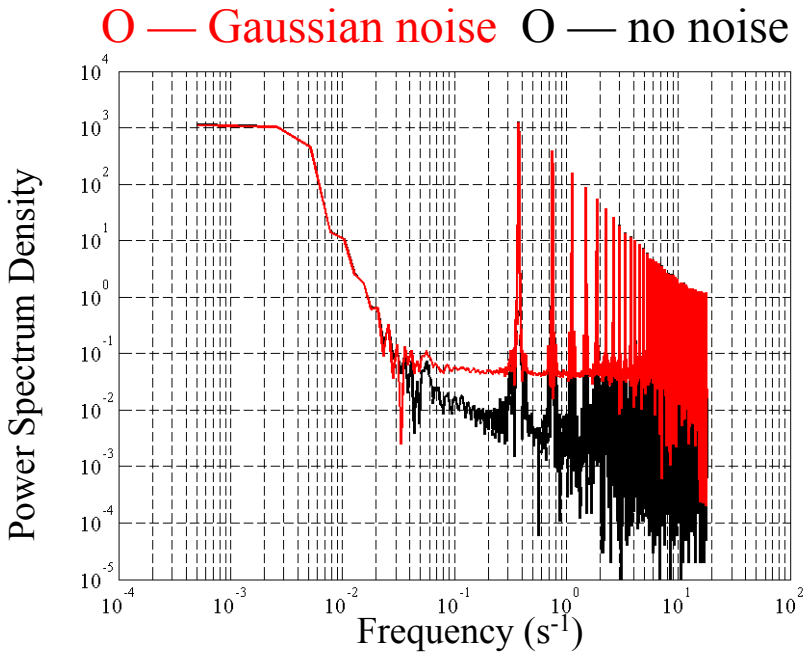
A 1/*f* flicker noise feature of the ATMS power spectrum within the frequency range (10^{-2} -10^{-4} s^{-1}) is significantly reduced after striping noise mitigation (SNM).

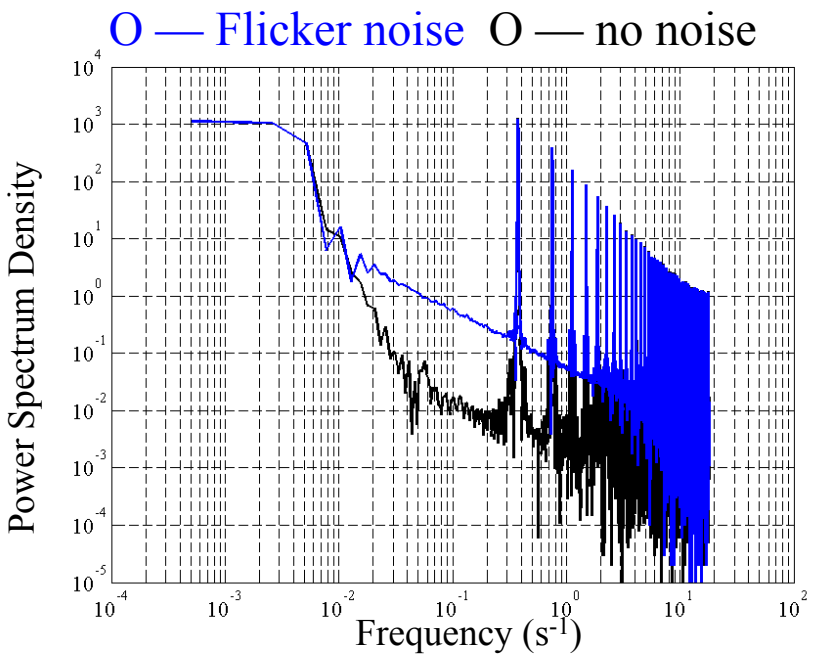
NOAA-18 AMSU-A channel 9

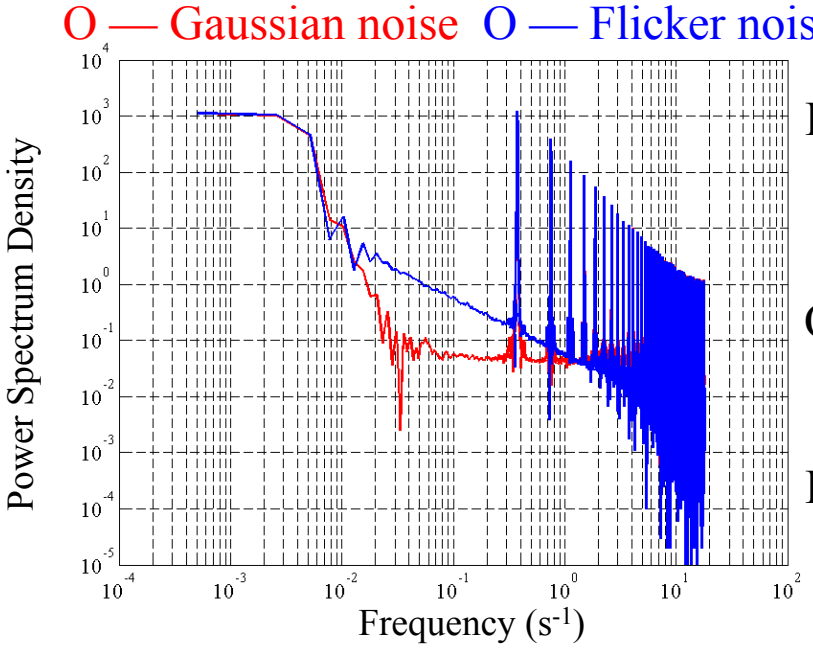


The AMSU-A power spectrum does not have a 1/*f* flicker noise feature within the frequency range (10^{-2} -10^{-4} s^{-1}). Applying the PCS/EEMD algorithm anyway has negligible effect on AMSU-A spectrum.

O-B PSDs When O Is Simulated with Gaussian and Flicker Noise







B — Brightness temperature simulations for ATMS channel 8 with GFS input on May 1, 2014

O — $\begin{cases} B_2 \\ B_2 + \text{Gaussian noise } (\mu = 0, \sigma = 0.283\,\text{K}) \\ B_2 + \text{Flicker noise } (\mu = 0, \sigma = 0.283\,\text{K}) \end{cases}$

B_2 — Brightness temperature simulations for ATMS channel 8 with GFS input on May 5, 2014

Can ATMS striping noise be removed by boxcar or triangular filters by simply increasing the filter span?

Boxcar Filter

$$\bar{T}_{b,i} = \sum_{j=-n}^{n} \frac{1}{2n+1} T_{b,i+j}$$

$$\mathbf{w}_7^{\text{boxcar}} = \left(\frac{1}{15}, \frac{1}{15}, \cdots, \frac{1}{15} \right)$$

$$\mathbf{w}_{17}^{\text{boxcar}} = \left(\frac{1}{35}, \frac{1}{35}, \cdots, \frac{1}{35} \right)$$

Constant weighting

Triangular Filter

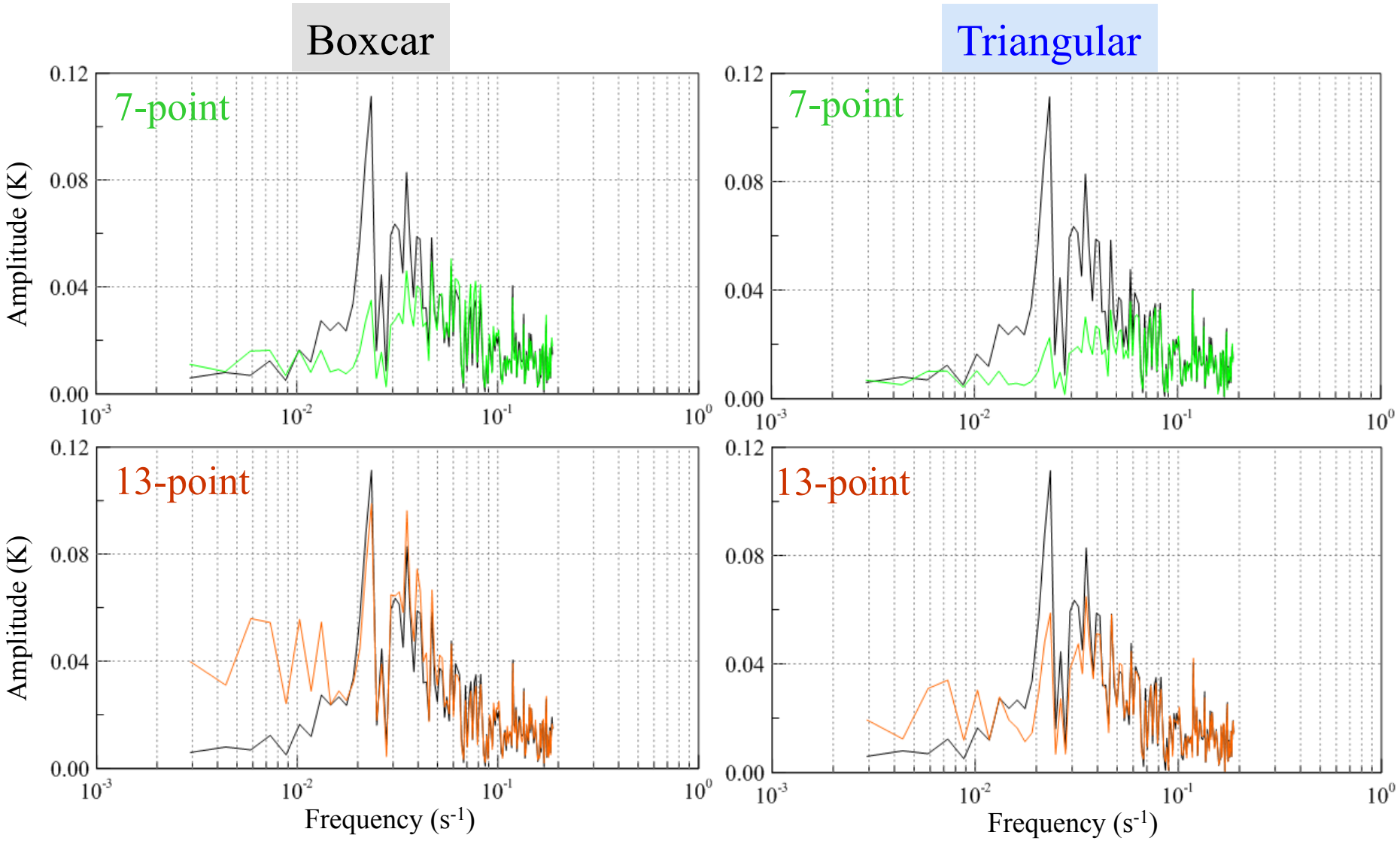
$$\bar{T}_{b,i} = \sum_{j=-n}^{n} \frac{n+1-|j|}{(n+1)^2} T_{b,i+j}$$

$$\mathbf{w}_7^{\text{triangular}} = \left(\frac{1}{64}, \frac{2}{64}, \cdots, \frac{7}{64}, \frac{8}{64}, \frac{7}{64}, \cdots, \frac{1}{64} \right)$$

$$\mathbf{w}_{17}^{\text{triangular}} = \left(\frac{1}{324}, \frac{2}{324}, \cdots, \frac{17}{324}, \frac{18}{324}, \frac{17}{324}, \cdots, \frac{1}{324} \right)$$

Triangular weighting

Noise Spectra Removed by Boxcar and Triangular Filters



Increasing the filter span does make the boxcar and triangular filters to be more effective in removing the striping noise but the larger scales of weather signals could be altered.

Step II: Develop a symmetric filter to remove striping noise

The first PC coefficient

$$\{u_{1,k}\}\ (k=1,2,\cdots,K)$$

The filtered first PC coefficient

$$\bar{u}_{1,k}=\sum_{n=-N}^{N}\alpha_n u_{1,k+n},\quad \alpha_n=\alpha_{-n}$$

$$\begin{cases}\min_{\alpha_n} J=\min\sum_{k=1}^{K}\left(\sum_{n=-N}^{N}\alpha_n u_{1,k+n}-\bar{u}_{1,k}^{eemd}\right)^2\\ \sum_{n=-N}^{N}\alpha_n=1,\quad \alpha_n=\alpha_{-n}\end{cases}$$

where $\bar{u}_{k,1}^{eemd}=u_{k,1}-\sum_{m=1}^{L}IMF_m(k)$

$$u_{1,k}=\sum_{m=0}^{K-1}C_m e^{-i\frac{2\pi mk}{K}}\qquad \bar{u}_{1,k}=\sum_{m=0}^{K-1}\bar{C}_m e^{-i\frac{2\pi mk}{K}}$$

$$r_m=\sum_{n=0}^{N}\alpha_n\cos(2\pi f\Delta t)$$

$$\bar{C}_m=r_m C_m,\ f=\frac{m}{K\Delta t},\ \Delta t=\frac{8}{3}s$$

$$T_{b,k,i}^{destriping}=e_{1,i}\sum_{n=-N}^{N}\alpha_n u_{1,k+n}+\sum_{j=2}^{96}e_{j,i}u_{j,k}$$

$i=1,2,\cdots,96$ represents scan position

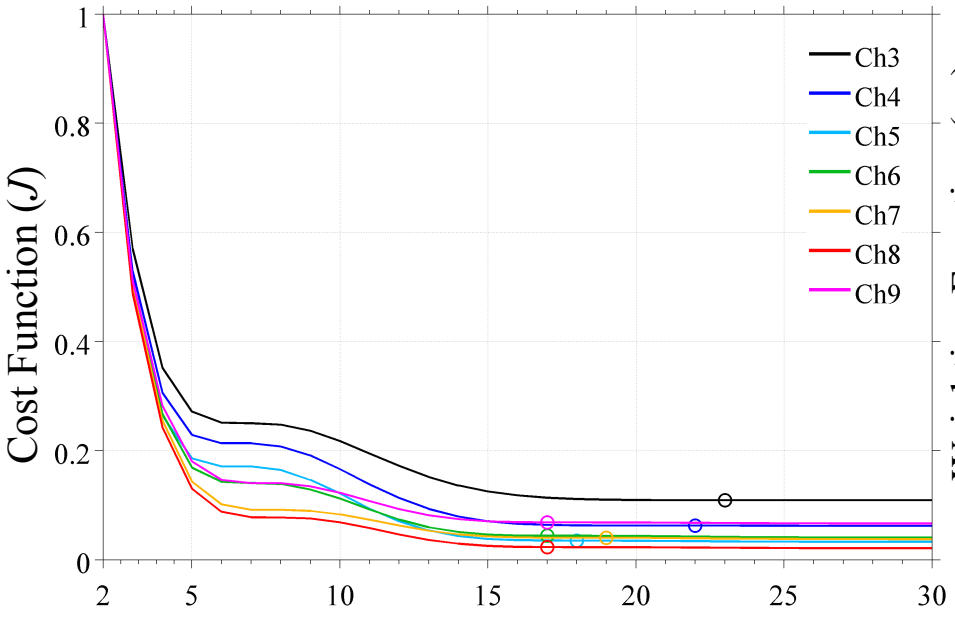
$k=1,2,\cdots,K$ represents scan line

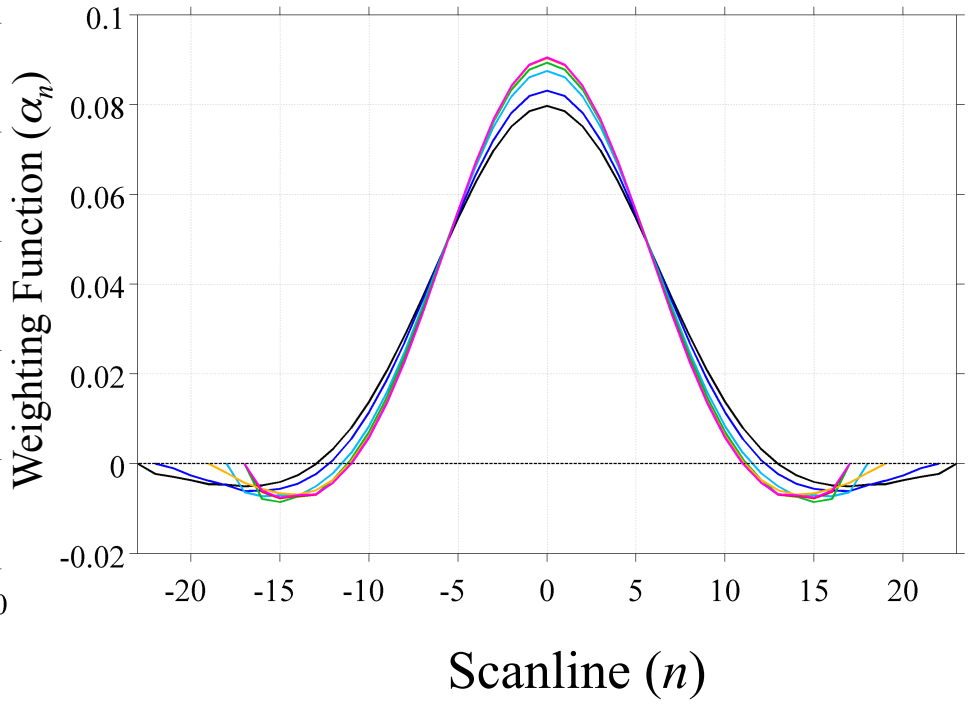
The Optimal Striping Filters: Numerical Results

$$J = \sum_{k=1}^{K} \left(\sum_{n=-N}^{N} \alpha_n u_{1,k+n} - \bar{u}_{1,k}^{eemd} \right)^2$$

Optimal Weights

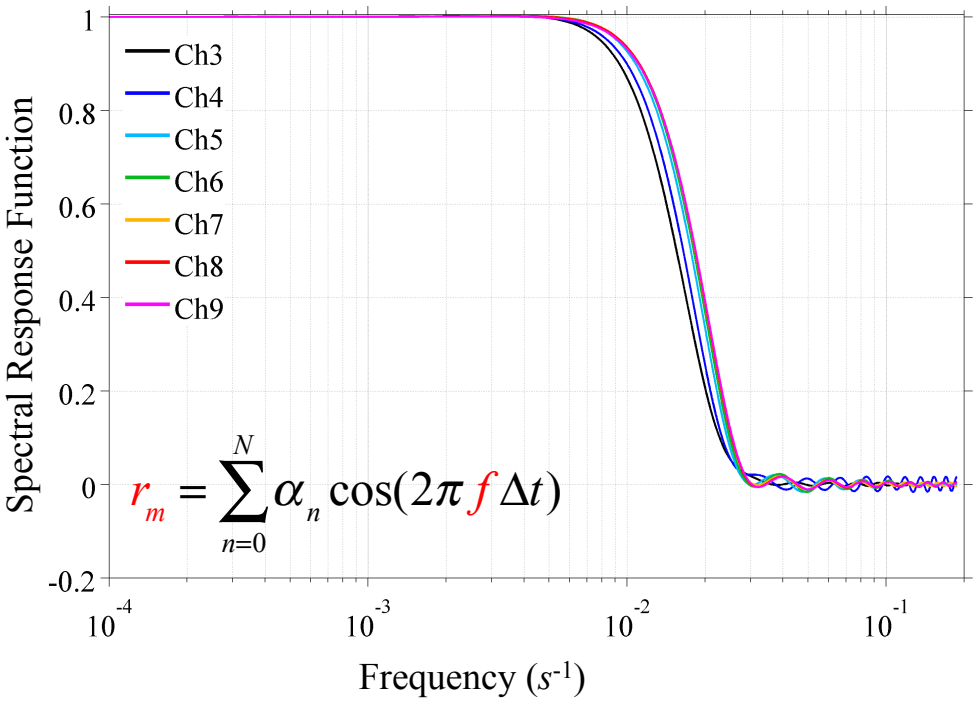
$$\alpha_{n,ch}$$



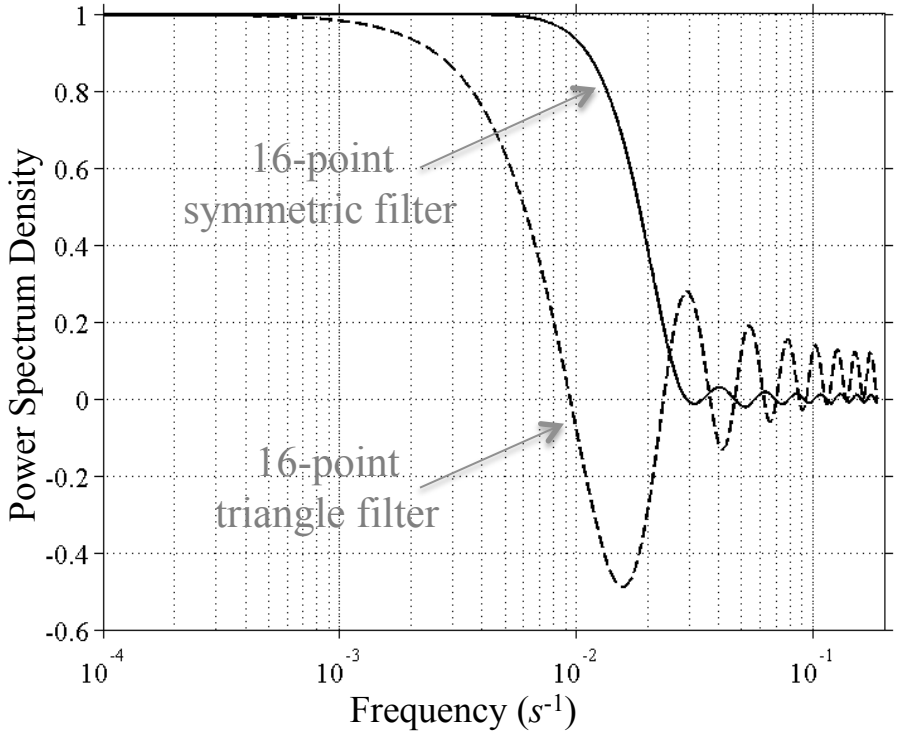


The Spectral Response Function of the PCS/SymFilter

Striping Filters for ATMS Channels 3-9



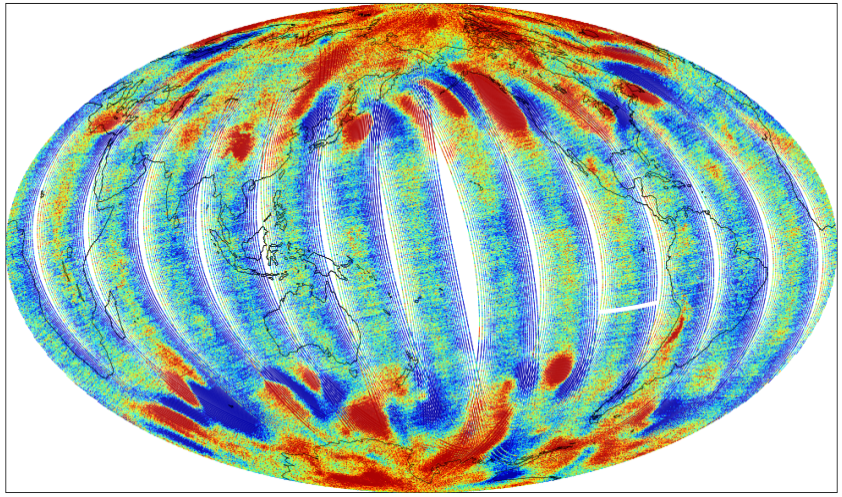
Comparison with a Triangular Filter



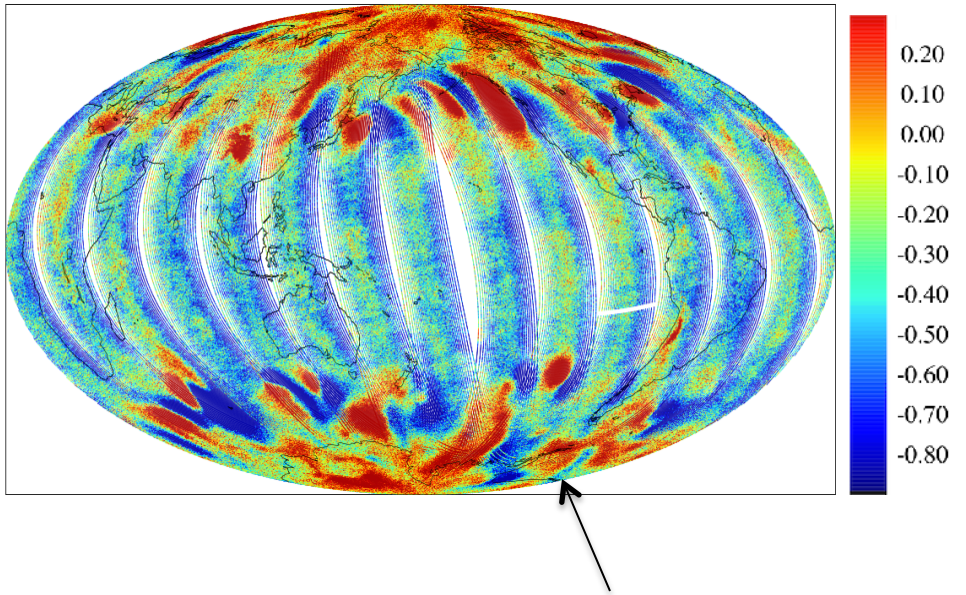
This is a set of optimal filters for ATMS radiances designed to smooth out the striping noise but not to alter lower frequency weather signals.

Global O-B Distributions of ATMS Channel 8

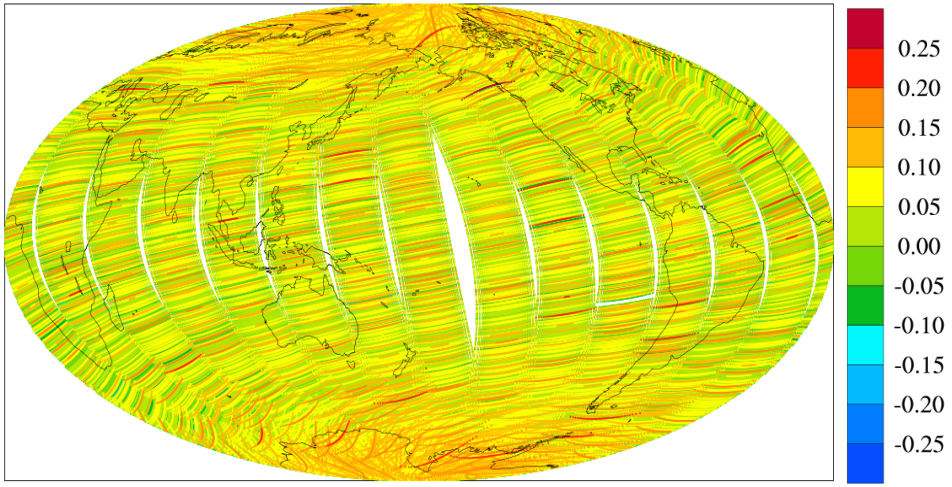
Before de-striping



After de-striping



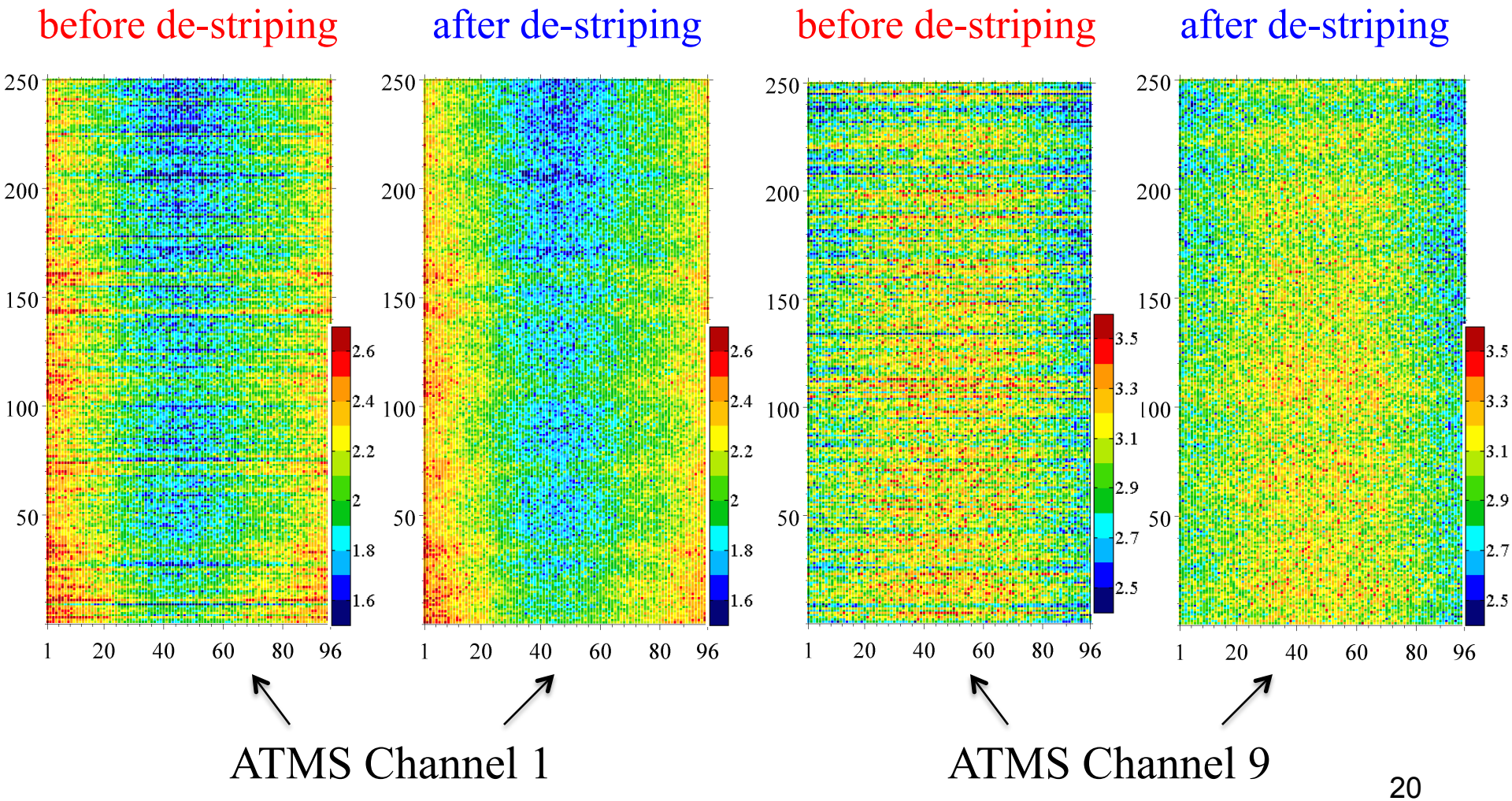
Striping noise filtered



Striping noise is not visibly seen anymore in the global O-B field after de-striping using the PCA/ SymFilter algorithm.

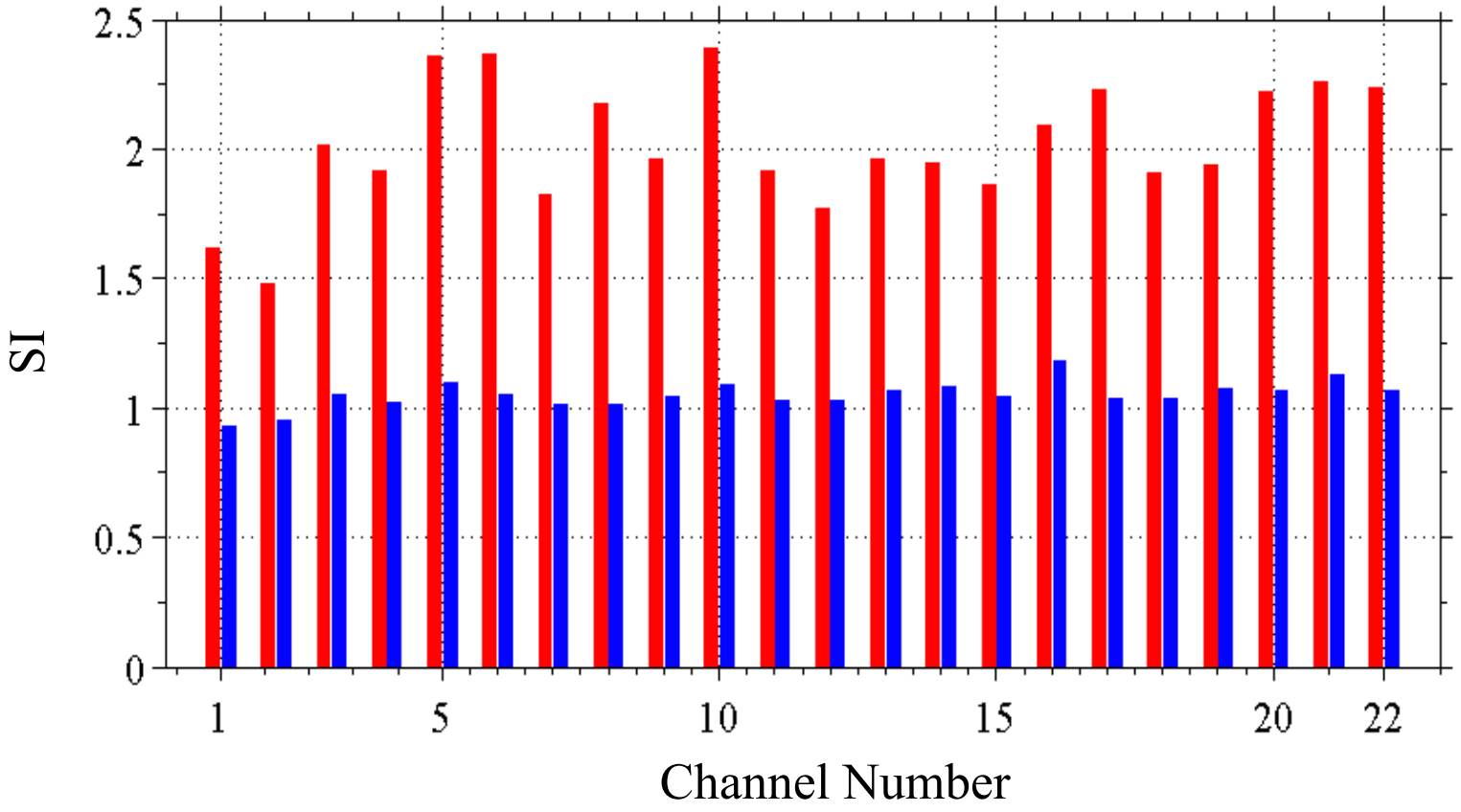
Ma Y. and X. Zou (2015)
J. Geophy. Res., **120**, 6634-6653.

Pitch-Over Maneuver Data before and after Striping Mitigation Using the PCA/SymFilter Algorithm



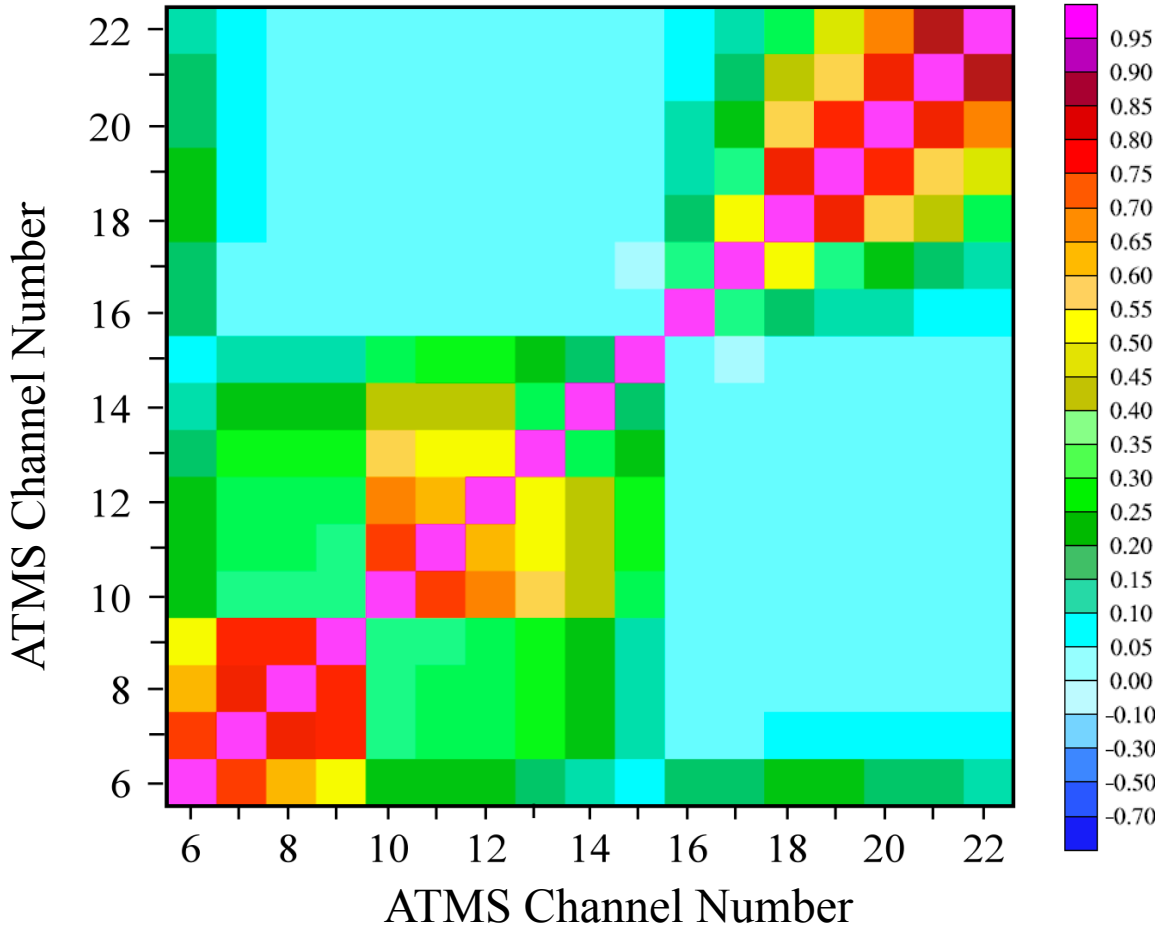
Striping Index (SI)

$$SI = \frac{\sigma^2_{along-track}}{\sigma^2_{cross-track}}$$



SI is significantly reduced to one for ATMS all channels.

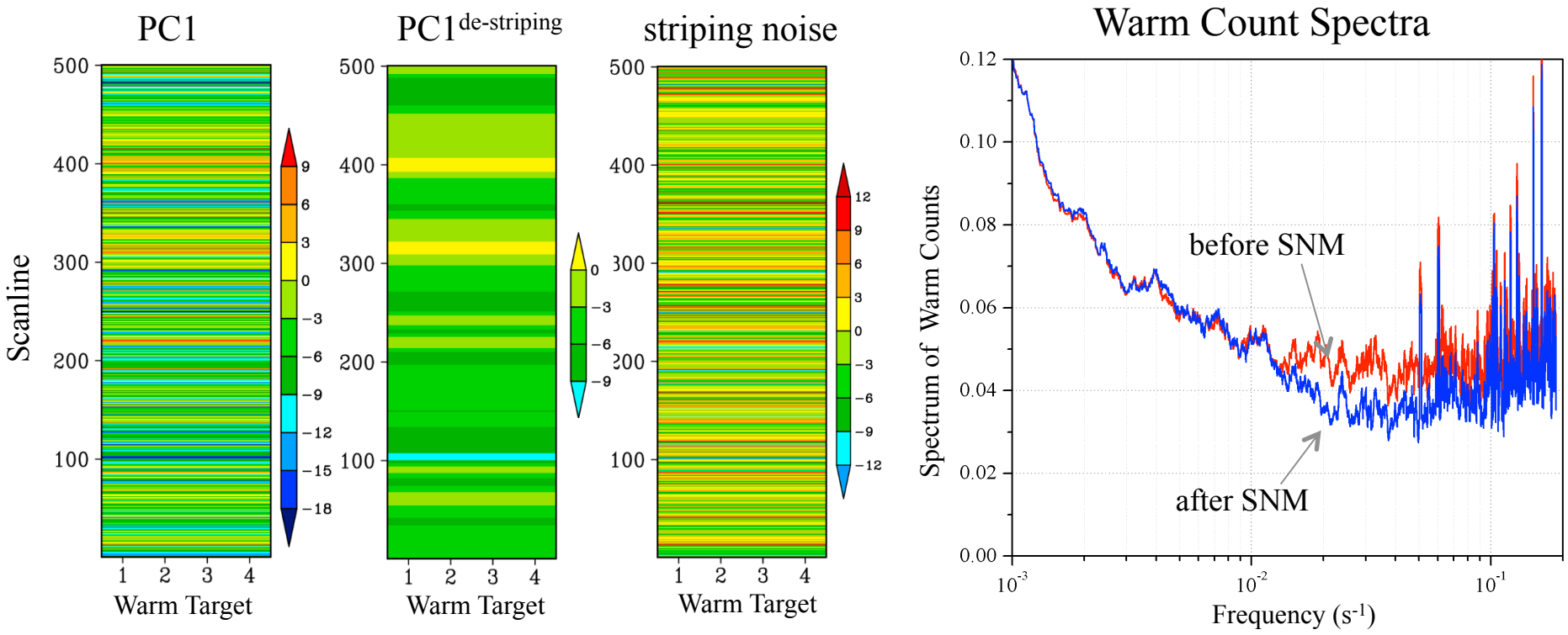
Channel Correlations of Striping Noise



Global data on
February 24, 2012

Striping noise is correlated among channels which share the same feed horn: Channel 6-15; Channels 17-22.

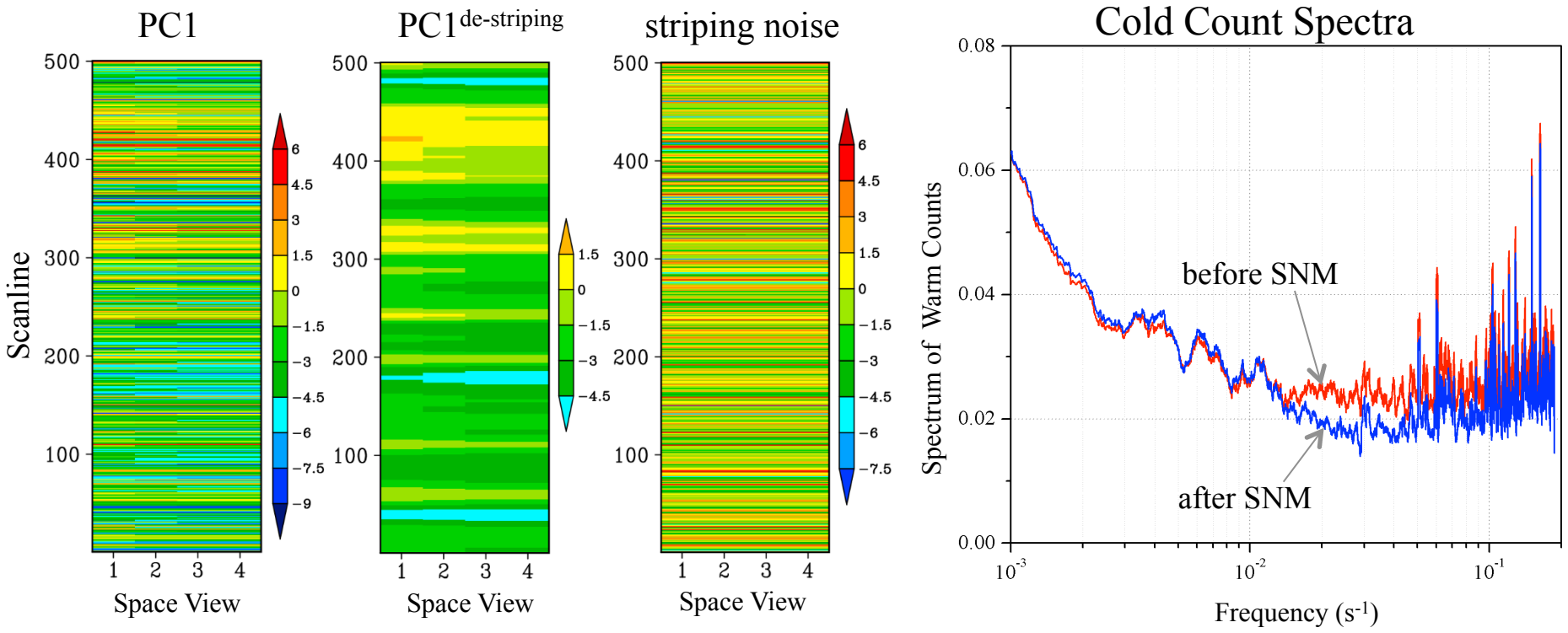
Striping Noise in ATMS Calibration Counts of Four Warm Targets



A 1/*f* flicker noise feature within the frequency range (10^{-2} -10^{-4} s^{-1}) in the warm count spectrum is significantly reduced after de-striping.

The averaged warm count value of 19562.86 over 32364 scan lines for ATMS channel 8 is subtracted.

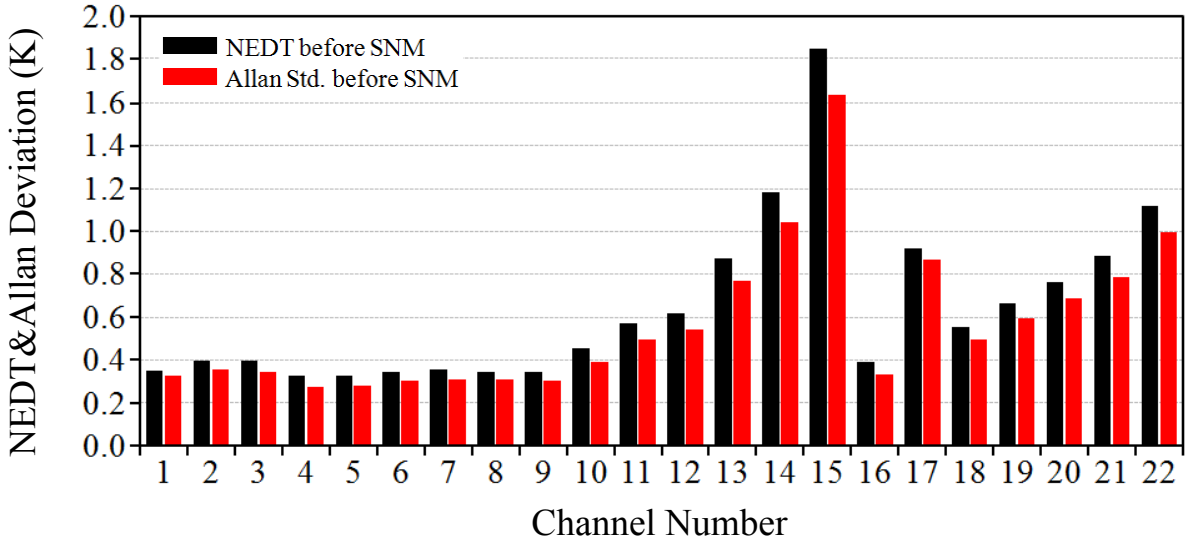
Striping Noise in ATMS Ch 8 Calibration Counts of Four Space Views



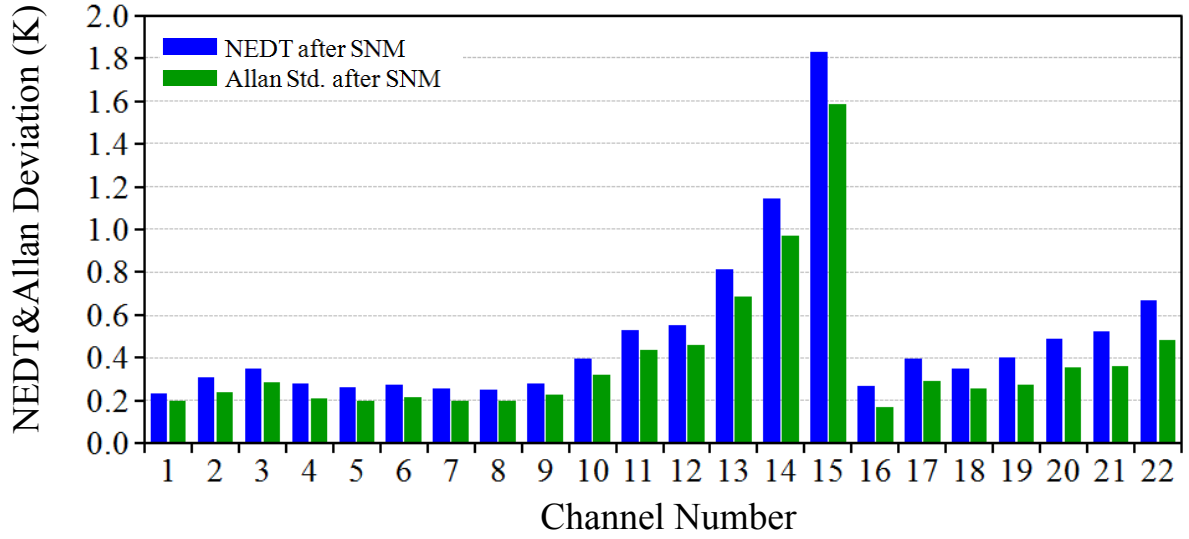
A 1/*f* flicker noise feature within the frequency range (10^{-2} -10^{-4} s^{-1}) in the cold count spectrum is significantly reduced after de-striping.

The averaged cold count value of 10459.79 over 32364 scan lines for ATMS channel 8 is subtracted.

Impact of Striping Noise on ATMS Noise Characterization

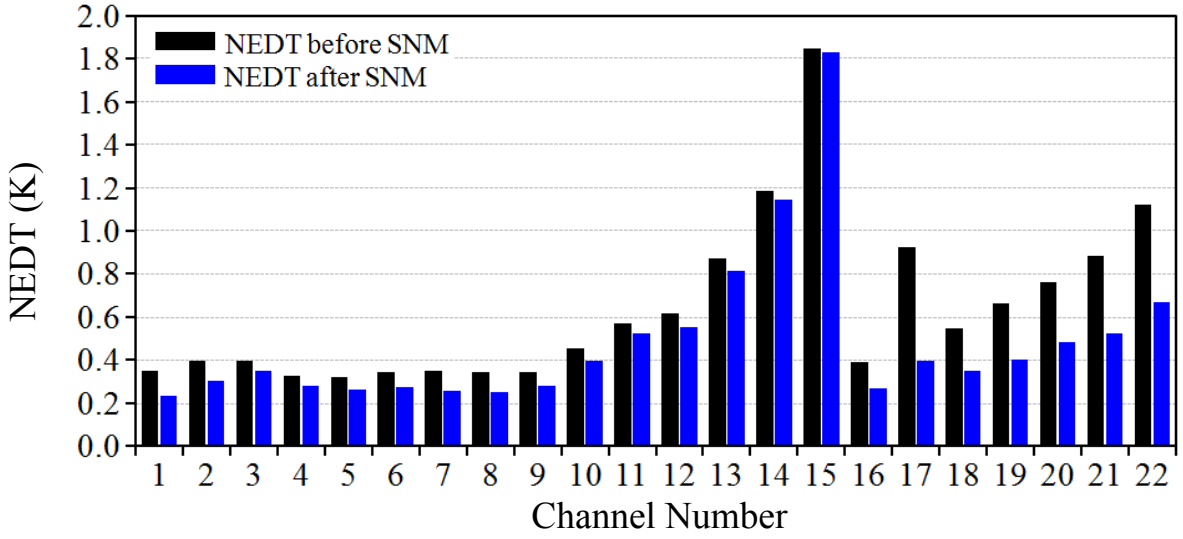


Before striping noise mitigation (SNM)

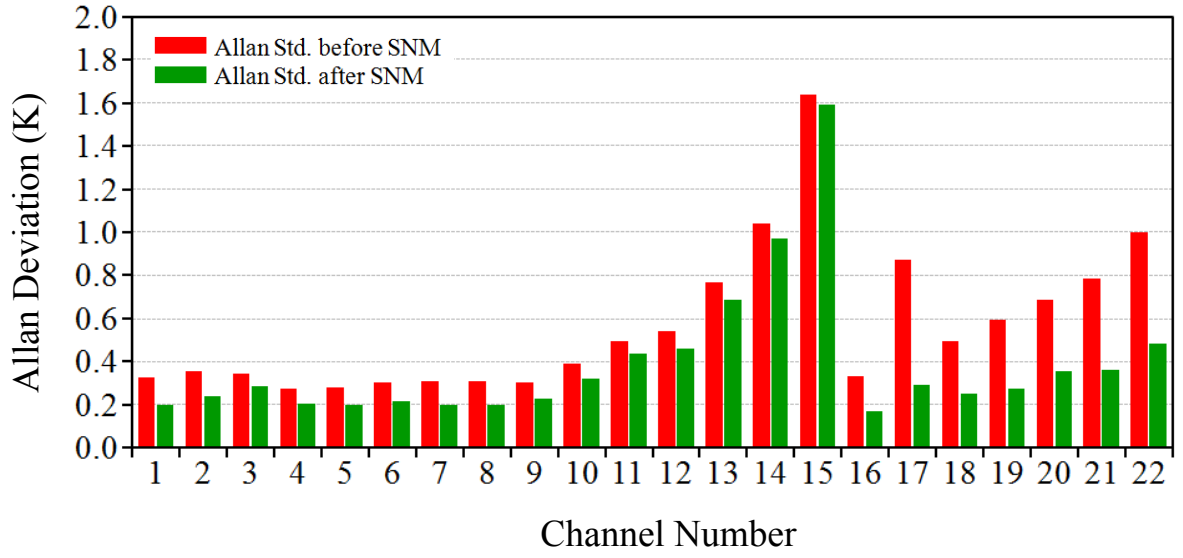


After SNM

Impact of Striping Noise on ATMS Noise Characterization



NEDT



Allan Deviation

Accomplishments

- ATMS striping noise magnitude in earth scene observations is quantified and verified by pitch maneuver data with consistency
- A striping mitigation algorithm that is feasible for an operational implementation is developed and tested
- 45-day ATMS de-striped radiance data were generated and delivered to several NWP centers (EMC, ECMWF etc.) for testing the striping noise impacts on ATMS data assimilation and subsequent NWP
- The PCA/EEMD algorithm for theoretical analysis of striping noise were published in the JPSS JGR special issue

  Qin, Z., X. Zou and F. Weng, 2013: Analysis of ATMS and AMSU striping noise from their earth scene observations. *J. Geophy. Res.*, **118**, 13,214-13,229.

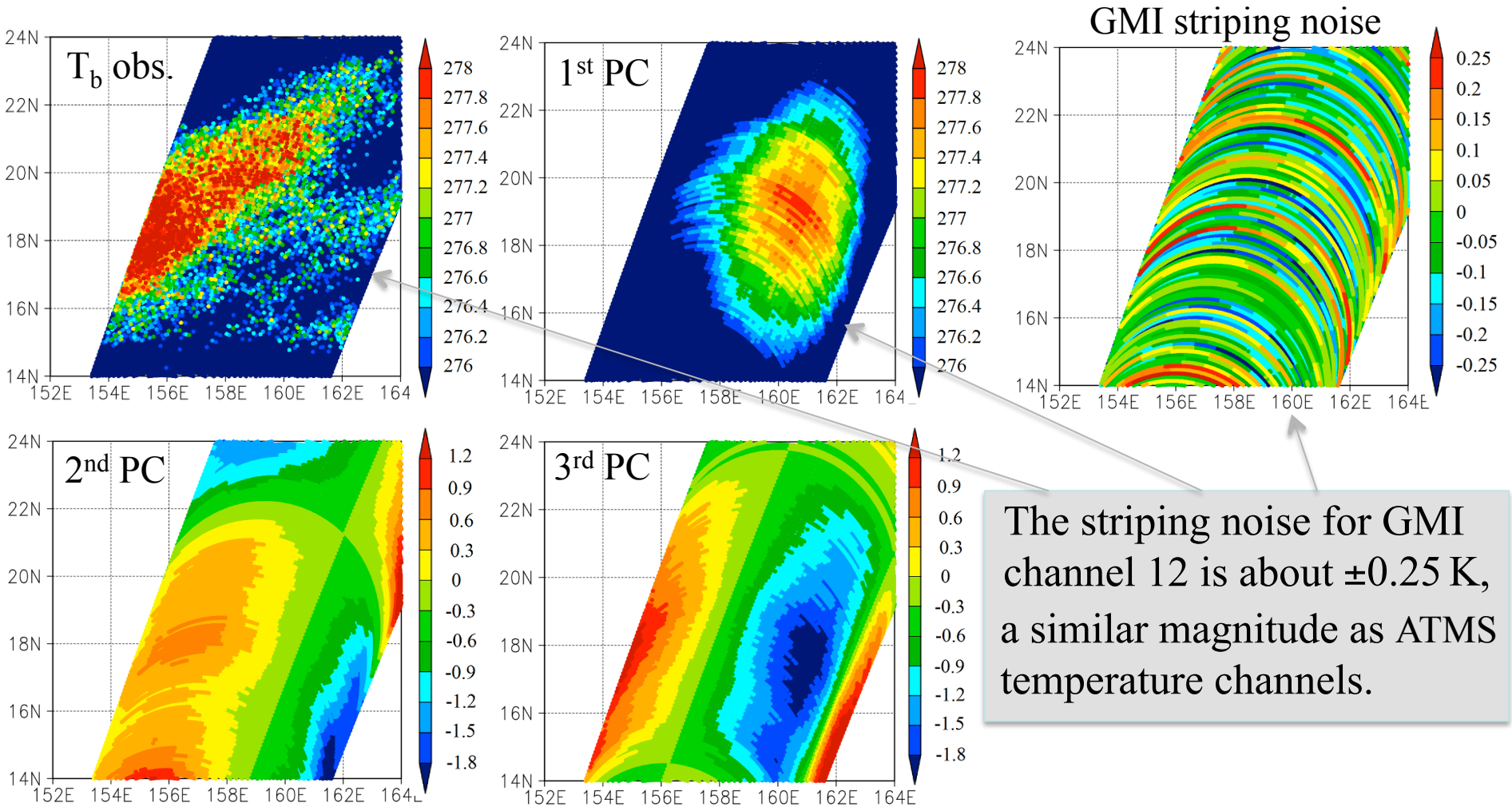
- The PCA/SymFilter algorithm for operational implementation of striping mitigation was published in JGR last month

  Ma Y. and X. Zou, 2015: Striping noise mitigation in ATMS brightness temperatures and its impact on cloud LWP retrievals. *J. Geophy. Res.*, 120, 6634-6653.

Planned Future Work

- Prepare for a striping noise evaluation for J1 ATMS channels if needed
- Conduct striping noise analysis and mitigation for other satellite sensors such as CrIS, GMI, AMSR2
- Complete documentation of the impacts of striping noise on ATMS NEDT noise characterization using both the standard deviation and the Allan deviation

A First Look at GPM Microwave Imager (GMI) Data



The striping noise for GMI channel 12 is about ±0.25 K, a similar magnitude as ATMS temperature channels.

An along-track noise oscillations seem to also exist in radiance measurements for GMI channel 12 (183.1 ± 3 GHz).

Acknowledgement

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